

# **PEER REVIEW**

## **PROPOSED CALIFORNIA PHASE THREE REFORMULATED GASOLINE REGULATIONS**

Prepared for California Air Resources Board  
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## INTRODUCTION

The California Air Resources Board (ARB) requested an independent peer review of the staff report on the proposed California phase three reformulated gasoline regulations.\* The scope of work for this peer review is shown below.

...a scientific peer review of the staff report including revisions to the ... Predictive Model, ...

A peer review of the proposed CaRFG3 regulations will be performed to provide independent confirmation of the scientifically-based rationale used in the ARB staff report which supports the recommended changes to the existing California Phase 2 Reformulated Gasoline (CaRFG2) regulations and the ARB Predictive Model.

A scientific peer review will be provided on the staff recommendations in the staff report including both the policy and technical basis for the proposed revisions in the CaRFG3 regulations and the ARB Predictive Model.

The proposed regulations for phase three California reformulated gasoline (CaRFG3) resulted from the executive order of Governor Davis to eliminate the use of methyl tertiary butyl ether (MTBE) from gasoline in California. The stated goal of the regulations was to provide flexibility in meeting regulations for reformulated gasoline without MTBE while preserving the emission benefits of that fuel. Another objective was an increase in the emission benefits where economically feasible.

The report provided for review consists of an executive summary and seven chapters listed below:

- Background
- Gasoline composition and properties of CaRFG2
- Proposed CaRFG3 regulations
- Other issues considered
- Economic effects of the proposed CaRFG3 regulations
- Environmental effects of the proposed CaRFG3 regulations

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\* California Air Resources Board, "Proposed California Phase 3 Reformulated Gasoline Regulations. Proposed Amendments to the California Reformulated Gasoline Regulations, Including a December 31, 2002 Prohibition of Using MTBE in Gasoline, Adoption of Phase 3 Gasoline Standards, a Phase 3 Predictive Model and Other Changes. Staff Report: Initial Statement of Reasons," October 22, 1999.

The report also contains sixteen appendices. Supplementary materials, including the staff reports for the previous regulations for California reformulated gasoline were also provided as background materials for this review.

The proposed regulations on fuel properties are summarized in Table III-1 on page 24 of the report (also in Table 2 of the executive summary). Table 1, below, is taken from the executive summary table. Refiners can satisfy the current and proposed regulations in four different ways:

1. Meet the flat limits for all gasoline sold.
2. Meet the averaging limits for average gasoline sales.
3. Use a predictive model to define refinery-specific limits (flat, averaging or a combination of the two).
4. Use vehicle emission testing to define refinery-specific limits (flat, averaging or a combination of the two).

Regardless of the compliance option selected, all gasoline sold must meet the cap limits. Most of the gasoline currently sold in California complies with the regulations by use of the predictive model. The revision to the predictive model is another important component of the proposed regulations.

The proposed regulations also implement the Governor's executive order to ban the use of MTBE in gasoline by setting maximum limits for the MTBE content. These limits are shown in Table 2. This phase-in of the limits is intended to allow for the removal of residual MTBE in the gasoline distribution system. The use of any alcohols or ethers, except ethanol, is also prohibited.

Additional changes include the new requirement for a maximum driveability index shown in Table 1, and changes to the regulations governing blending stocks to which oxygenated fuel components will be added before final sale. A new predictive model has also been developed as part of the proposed regulations.

The report provides a clear description of the proposed regulations. The changes are summarized effectively in the executive summary and many details of the report are placed in the appendices. The major focus of the regulations, the elimination of MTBE from gasolines in California, is in response to Executive Order D-5-99, signed by Governor Davis on March 25, 1999. That executive order directed the ARB to "adopt California Phase 3 Reformulated Gasoline (CaRFG3) regulations that will provide additional flexibility in lowering or removing the oxygen content requirement and maintain current emissions and air quality benefits and allow compliance with the State Implementation Plan (SIP)."

<b>Table 1</b> <b>Proposed Property Limits for CARFG3 Effective December 31, 2002</b>						
Property	Flat Limits		Averaging Limits		Cap Limits	
	Original	Proposed	Original	Proposed	Original	Proposed
RVP (psi)	7.0	7.0 <sup>(1)</sup>	N/A <sup>(2)</sup>	no	7.0	6.4-7.2
Benzene (%v)	1.00	0.80	0.80	0.70	1.20	1.10
Sulfur (ppmw)	40	20	30	15	80	60/30 <sup>(3)</sup>
Aromatics (%v)	25	no	22	no	30	35
Olefins (%v)	6.0	no	4.0	no	10	no change
Oxygen (%w)	1.8 to 2.2	no	N/A <sup>(2)</sup>	no	0 to 3.5	0 to 3.7 <sup>(4)</sup>
T50 (°F)	210	211	200	201	220	225
T90 (°F)	300	305	290	295	330	335
DI <sup>(5)</sup>	none	1225	N/A <sup>(2)</sup>	N/A <sup>(2)</sup>	none	none
<b>Notes:</b> This table is taken from Table III-1, page 24, of the ARB staff report on proposed phase three reformulated gasoline regulations. Property limits are maximum values except for oxygen, which is a range. <sup>(1)</sup> Proposed Reid vapor pressure (RVP) limit is 6.9 psi if using the evaporative element of the predictive model. <sup>(2)</sup> Not Applicable. <sup>(3)</sup> Limit of 60 ppmw effective December 31, 2002; 30 ppmw on December 31, 2004. <sup>(4)</sup> The cap limit is 3.7 %w if the gasoline contains more than 3.5 %w oxygen, but no more than 10%v ethanol. <sup>(5)</sup> The driveability index, DI = 1.5 (T10 °F) + 3 (T50 °F) + (T90 °F) + 20 (%w oxygen).						

<b>Table 2</b> <b>Dates for MTBE Limits</b>	
Effective Date <sup>(1)</sup>	MTBE Limit
December 31, 2002	0.3 %vol
December 31, 2003	0.15 %vol
December 31, 2004	0.05 %vol
<sup>(1)</sup> These effective dates apply to refiners and importers. Up to 90 additional days are allowed for downstream fuel distribution and sales facilities.	

The discussion in the report presents the background and rationale for the proposed regulations. However, there is only a limited discussion of alternative proposals. For example, why was the proposed T10 flat limit of 211°F selected instead of an alternative value? In addition, the proposal is not a conventional one in that the main objective of the proposal – the removal of MTBE from gasoline – is not intended to address an air quality problem.

The staff report notes several instances where additional information is still being developed, including costs and other environmental effects. This additional information should allow the Board to make a better informed decision.

This review is divided into five sections: (1) this introductory section, (2) a discussion of specific chapters in the report, (3) an analysis of the proposed changes in the predictive model, (4) a review of the report appendices and (5) a conclusions section. The discussion of the staff report provides some explanation of the proposed changes followed by a discussion of their scientific and policy rationale.



## SPECIFIC COMMENTS ON REPORT CHAPTERS

### Executive Summary, Background, and Current Gasoline Data

The executive summary provided an understandable overview of the entire report. It is useful for both the reader who wants an overview without reading the remainder of the report and the reader who plans to read the entire report.

Chapter one discusses the background to the present regulations. It considers the rationale for fuel regulations, the emission impacts of the current (phase two) regulations, the relationship to federal reformulated gasoline regulations, mobile source emission inventories, and the attainment status of various areas in California for ozone, CO, and particulate matter.

Chapter two presents various statistics on gasoline consumption and notes that the increasing consumption of gasoline in California will lead to increasing imports in the future. This chapter also discusses the historical properties of gasoline in California and estimates the effect of the compliance margin. This margin, which is the difference between the regulatory standard and the actual fuel properties, is used by refiners to ensure full compliance with the regulations. This difference between the regulatory limit and the actual fuel properties, which leads to an emissions benefit, is generally present in other environmental regulations.

This chapter also discusses the driveability index. This index, which is a measure of the smoothness of driving, was initially measured by trained drivers. From these initial measurements a correlation between the driveability index and fuel properties was developed.

$$\text{Driveability Index (DI)} = 1.5 (T_{10} \text{ } ^\circ\text{F}) + 3 (T_{50} \text{ } ^\circ\text{F}) + (T_{90} \text{ } ^\circ\text{F}) + 20 (\%w \text{ oxygen}).$$

Much of the data on DI reported in this section was based on fuel data that did not have values for T10 or oxygen. The T10 effect was estimated using a regression analysis reported in Appendix H of the ARB staff report. This regression analysis is discussed on page 22 of this review.

The discussion of the driveability index contains three statements about the desired value for the driveability index.

- DI values “generally below 1200 to 1250 are desired, while higher DI’s can adversely affect vehicle driveability and emissions.”

- “The ASTM has adopted a DI standard of 1250 without the correction for oxygen.” This is equivalent to a DI of 1300 for a fuel with 2.5%wt oxygen.
- “The auto manufacturers believe that a DI, with oxygen correction, of 1200 is needed to ensure good driveability.”

The standard value of 1225 selected by the staff appears to be an arbitrary choice within this range of desirable values. It ensures that gasolines produced to meet the CaRFG3 standards will be close to the 1200 value that the automobile manufacturers say is needed, but will be less than the 1300 value allowed by the ASTM specification.

## Proposed Regulations

Chapter three discusses the proposed regulations for California phase three reformulated gasoline. This discussion generally presents a description of the changes and their rationale. Quantitative information on the changes is presented in later chapters. The actual regulatory language, showing the changes from the current language is presented in Appendix A. The proposed changes to the predictive model are discussed in the next section of this review.

### Prohibition of MTBE

The prohibition of MTBE includes explicit language in section 2262.6(a)(1) that bans the sale of gasoline “which has been produced” with the use of MTBE. This is further implemented by the specific concentration limits on MTBE shown in Table 2 on page 3 of this review. The phase down in the concentration limits allows for the gradual elimination of residual MTBE in the gasoline distribution system. Although this is qualitatively a sound approach, no rationale is provided for the specific limits provided in the proposed regulation. An additional period is allowed for MTBE to work through the distribution system after each step decrease in the allowed MTBE level. The effective dates in Table 2 apply only to refiners and importers. Ninety days are allowed before the limit applies to all downstream facilities.\* This schedule is consistent with the one used for the implementation of the phase two regulations in 1996.

This same approach of delaying the application of limits to various portions of the distribution system is also applied to the more stringent cap limits for benzene and sulfur described below. The rationale is similar to the phase-in for the MTBE limits. Here again, the staff experience with a similar phasing of limits in the distribution system for the introduction of phase two gasoline in 1996 forms an effective basis for the current phase-in approach. The phasing approach is not used in the cases where the cap limits become less stringent.

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\*There is an initial 45-day period after which the limit applies to all facilities except bulk plants, retail outlets and bulk purchases-consumer facilities. In addition, special provisions for the effective date apply to low-throughput facilities.

In addition to the prohibition of MTBE, there is a conditional prohibition, effective with the initial prohibition of MTBE on December 31, 2002, against the use of any ether or alcohol, except ethanol. The prohibition applies unless the compound or compounds are found “environmentally benign” through a study of the impact on all environmental media. This approach is a reasonable one. Additional studies of ethanol, the only oxygenated fuel component allowed under the present regulations, are currently under way. The proposed regulations provide a cautionary approach against the use of compounds whose effects do not have the extensive study applied to MTBE. However, it provides a mechanism for use of such compounds once appropriate studies have been completed.

### **Proposed Specification for Phase three Reformulated Gasoline**

The changes in the specifications for phase three reformulated gasoline are summarized in Table 1 on page 3 of this review. The rationale for the proposed changes is discussed below.

*Distillation Temperature and Aromatics Limits* – Slight increases in these limits have been proposed to provide more flexibility to refiners’ compliance after the elimination of MTBE as a blending component. These increases are relatively small (1°F to 5°F for distillation temperatures and 5%v for the aromatics cap). However, the cost analysis chapter notes that every 1°F increase in T50 can provide a 1 to 2% increase in gasoline volume.

*Reduced sulfur and benzene limits* – Several recent studies have shown a significant impact of gasoline sulfur content on exhaust emissions.\* The relative effect of sulfur is particularly important for vehicles with very low emissions. The phase two regulations have already set very low sulfur limits for gasoline so that the proposed changes will have only a small effect on the total emissions inventory. (In the chapter on cost the staff states that most of the emission benefit is due to the change in the sulfur specification. However, the emissions analyses presented later do not show the effects of individual changes on the overall emissions change.)

The reduced benzene levels in phase three gasoline will reduce the emissions of benzene, a known human carcinogen, from both fuel evaporation and exhaust emissions.

*Driveability Index* – See the discussion above, starting on page 5, for the discussion of this new requirement.

### **Proposed Requirements for Oxygenate Blending Feedstocks**

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\*These studies are described in the April 1999, U. S. Environmental Protection Agency (EPA) regulatory support document for the Tier II/gasoline sulfur rulemaking. Additional information is available in the May 1998 EPA staff report (EPA 420 F 98-022) on gasoline sulfur issues.

A special enforcement procedure is applied to California reformulated gasoline blend stock for oxygenate blending, known as CARBOB. This procedure applies to gasoline blend stocks to which the oxygenated components are added at distribution terminals instead of at the refinery. In this case the blend stock leaving the refinery will not comply with the regulations although the final gasoline, after blending will do so. The CARBOB provisions have not been important in the past, but will become important in the future when ethanol is used as the oxygenated blending agent.

The staff has proposed several changes to the CARBOB provisions to make them easier to apply. Even with the proposed changes, the report notes that there are additional issues that will need to be considered after the phase three regulations are adopted. The CARBOB provisions are important to the *implementation* of the proposed regulatory changes. It is important that they provide the flexibility needed in the gasoline distribution system while ensuring that the final gasoline blends meet the standards adopted. However, these provisions should not affect the other portions of the report. In particular, the conclusions about costs and environmental benefits depend on the other parts of the proposal.

## **Other Changes**

As noted above, the proposed changes to the predictive model are discussed in the next section. Other changes proposed include the following:

- Increasing the maximum oxygen content to accommodate gasolines with up to 10%v ethanol. The present limit was designed to be consistent with the use of 10%v MTBE.
- Adjusting the effective date for RVP requirements in 2003 to ease the transition to phase three gasoline.
- Removing October from the list of months in which oxygenates must be added to fuels in the South Coast Air Basin for 2003 and later years. This provides greater flexibility in meeting the RVP standards during this month.
- Miscellaneous changes in regulatory structure, compliance plan deadlines, and technical details of the regulation.

These proposed changes do not have any significant effect on the regulation and generally improve the regulatory language.

## **Other Issues Considered**

The issues discussed in this chapter can be summarized as follows.

- The removal of the federal Clean Air Act requirement for year-round oxygen concentration in gasoline would be “[p]robably the single most effective action for an accelerated and least cost removal of MTBE in California.”
- The predictive model, as amended, is the best model to use for phase three reformulated gasoline. In particular, the report rejects the use of the U. S. Environmental Protection Agency (EPA) complex model and other alternatives including the consideration of a high-emitter correction and an off-cycle correction.
- There are insufficient data to analyze the effects of reformulated gasoline on off-road engines.
- The staff is continuing its consideration of additional issues related to CARBOB and the one small refiner who would be affected by the proposed regulatory changes.

The report states that the consideration of high-emitter and off-cycle corrections to the predictive model was not done due to lack of reliable data. There is little quantitative discussion to confirm these decisions. The consideration of off-road engine effects is presented in Appendix M of the staff report discussed on page 23 of this review.

## **Effects of Proposed Changes on Emissions**

The emission effects of the proposed regulations are studied using the predictive model. Initially, both the current predictive model and the proposed predictive model are used to compare the current and proposed flat limits. Both models show that the emissions of oxides of nitrogen, total hydrocarbons, and potency-weighted toxics decrease under the phase three flat limits. It would be interesting to see how each proposed change affects the results. This would give the reader more insight into the significance of each proposed change on the final emissions result.

The real-world emission differences between phase two and phase three gasoline were modeled using the phase three predictive model. This study compared the average 1998 in-use fuel properties with those of a “representative” future fuel. The latter were determined by staff based on their examination of the MathPro analysis of the refiners’ response to the elimination of MTBE and the assumption that the existing compliance margin under the phase two requirements would be continued with the phase three regulations. The future fuel was assumed to meet the flat limits for the phase three regulations.

The results of this real-world analysis are presented in Tables V-4 and V-5 of the staff report. These tables are confusing because they are a comparison of two analyses

that are comparisons of two fuels. The first analysis compares emissions from the assumed real-world phase three gasoline to the emissions from a baseline gasoline with properties exactly equal to the phase three flat limits. The second analysis compares the 1998 average in-use fuel to the same baseline. The difference between these two analyses is reported as a percentage in Table V-4 and as total tons per day (statewide) emissions\* in Table V-5.

The real-world emission difference for NO<sub>x</sub>, in calendar year 2005, is an 18.7 ton per day reduction for the in-use phase three fuel as compared with the 1998 in-use fuel. The reductions for exhaust hydrocarbons and evaporative hydrocarbons are 0.5 and 0.0 tons/day, respectively. Because no data are provided on the uncertainties in the predictive model, the statistical significance of the predicted emission differences cannot be determined.

The final set of analyses in this chapter examines the emissions that would be produced if the year-round federal requirement for a minimum oxygen content in gasoline were eliminated. The staff developed three fuel specifications for phase three gasolines with oxygen concentrations of zero, 2.7%v and 3.5%v. Each fuel was analyzed using the predictive model. Moving from the 3.5%v oxygen fuel to zero oxygen, for calendar year 2005, would decrease equivalent HC emissions\*\* (including the effects of CO reactivity) by 7.4 tons/day and increase NO<sub>x</sub> emissions by 38.7 tons/day.

## Economic Effects

The economic analysis considers the following components: capital cost for refinery modifications, increased costs of imported blend stocks, a cost savings from substituting ethanol for MTBE, a fuel economy penalty for ethanol use, costs to upgrade the distribution system to handle ethanol blending, and short-term cost increases due to temporary supply limits. The major component is an estimated cost of four cents per gallon from the refinery changes required by the proposed regulations. This includes both the amortization of the estimated capital cost of one billion dollars and increased operating and maintenance costs of \$400 million per year. (The amortization uses a 10% interest rate and a ten-year payout period, resulting in a capital recovery factor of 0.16.)

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\* The report does not state the geographic location of these emissions, but the cost effectiveness calculations in chapter six show that these must be statewide emission reductions.

\*\* Equivalent HC emissions, as used in this section of the report, is really a measure of ozone forming potential. Actual HC emissions *increase* by 8.5 tons per day. This is offset by a decrease in CO emissions. This CO decrease has the same effect on ozone as decreasing HC emissions by 15.9 tons per day. Thus the net effective change in HC emissions is a decrease of 15.9 - 8.5 = 7.4 tons/day.

The ARB staff estimates for implementing the complete phase three gasoline regulations range from four to six cents per gallon. There is also a possible additional cost of one cent per gallon in the first year due to supply problems. Most of the total cost is associated with the removal of MTBE from gasoline as directed by the governor's executive order. Many of the other changes in the regulations – the increases in distillation temperature levels and the aromatics cap, and the addition of an evaporative element to the predictive model – are designed to facilitate the removal of MTBE from gasoline. Thus these changes should lead to lower costs that would otherwise be present if the changes were not made. The two changes directed at improving air quality benefits are the reductions in benzene and sulfur levels. No estimates have been provided for the cost of lowering the benzene content of gasoline. The cost estimate for sulfur removal is discussed below.

ARB staff has used EPA data to estimate the cost of sulfur reduction. The EPA Tier II regulatory support document has estimated the cost of sulfur reduction to an average of 30 ppmw for various Petroleum Administration Districts for Defense (PADD). The EPA study did not include California because the ARB regulations already required low sulfur gasoline here. The EPA did estimate costs for refineries outside California in PADD 5, which includes California. The EPA cost estimates for various sulfur levels are shown in Table 3.

The ARB staff report says that their review of these data “indicates a cost of about 0.4 cents per gallon for a 20 ppmw decline to the [ARB] proposed sulfur limits.” This statement appears to use the proposed 20 ppmw change in the flat limits (40 ppmw to 20 ppmw) rather than the change in the averaging limits (30 ppmw to 15 ppmw) or the estimated change in the average sulfur concentration in the California gasoline pool (25 ppmw to 10 ppmw). It also seems to be based on the national average data that show a 0.2 cents per gallon cost for going from 40 to 30 ppmw. Doubling the figure would give the value of 0.4 cents per gallon for going from 40 ppmw to 20 ppmw. If this was the approach used, it does not account for local variation in the cost analysis.

<b>Table 3</b> <b>Gasoline Desulfurization Costs from EPA Tier II Cost Analysis<sup>(1)</sup></b>						
Average Sulfur Level (ppmw)	Costs for average sulfur level (cents per gallon) in various PADDs					
	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 <sup>(2)</sup>	Average <sup>(3)</sup>
80	1.5	1.0	1.0	2.0	2.0	1.2
40	2.1	1.2	1.3	2.8	2.3	1.5
30	2.3	1.4	1.4	3.2	2.8	1.7

**Notes:** <sup>(1)</sup>From Tier II/Sulfur Regulatory Support Document, EPA, April 1999, Table V-34, page V-47.  
<sup>(2)</sup>For PADD 5 refineries outside California only.  
<sup>(3)</sup>The national average is weighted by the production in each PADD.

This analysis is particularly important as it appears to account for the most significant expense associated with further air quality improvements. It is subsequently used to estimate the cost effectiveness. ARB staff does note that this 0.4-cent-per-gallon estimate is “consistent with information provided during discussions with individual refiners.” However, the staff report also notes that further reductions in sulfur level “would result in a significant cost escalation.” Thus the staff has selected the proposed sulfur level for phase three gasoline at a point that would incur some cost, but not include a significant cost escalation. Conceptually, this is an appropriate choice. However, the cost analysis for sulfur removal does not present enough information to make an independent judgement about how appropriate the selected sulfur level is.

## Environmental Effects

This chapter analyzes environmental effects that have not been discussed previously in the staff report. The most significant of these is the improvement in water quality from the elimination of MTBE in gasoline. The report notes that the substitution of ethanol for MTBE would potentially cause the same problems. Like MTBE, ethanol is soluble in water and, “based on theory, should travel at about the same rate as MTBE.” Ethanol is biodegradable, unlike MTBE, but ethanol may increase the solubility of other gasoline components in water. The Lawrence Livermore National Laboratory is currently studying the effects of widespread ethanol use in gasoline for the State Water Resources Control Board. The report on this study is scheduled to be issued on December 31, 1999.

The most significant air quality problem that would result from the phase three regulations arises from the potential for mixing gasoline with ethanol and gasoline without ethanol in vehicle fuel tanks. This becomes a problem only if there is significant opportunity for such mixing. Significant mixing could occur if there is a waiver from the year-round requirement for oxygenated compounds in gasoline. With such a waiver, it is likely that California gasoline production would have significant quantities of gasoline with ethanol and gasoline without ethanol. The blending of these two kinds of gasoline would increase the RVP, and hence the evaporative emissions, of the resulting mixture. The University of California, Davis, is currently



conducting a study on this issue for the ARB and the staff is committed to the development of “appropriate recommendations” to alleviate problems with the mixing of gasolines with and without ethanol “if a significant increase in emissions is occurring as a result of mixing ... in fuel tanks.”

The following environmental effects are also discussed in this chapter.

- Emissions associated with fuel production and delivery could change; such changes would be very small.
- The differences in air quality effects among gasoline with MTBE, gasoline with ethanol, and gasoline with no oxygenates, all meeting phase two standards, is very small. Additional work that is under way on this subject will be reported at the December Board meeting.
- “The proposed phase three regulations are not expected to increase emissions of greenhouse gases that contribute to global warming.”
- The proposed regulations should be “directionally health protective.” The Office of Environmental Health and Hazard Assessment (OEHHA) is evaluating the effect of potential public health aspects of the use of ethanol in gasoline.

In summary, the main environmental effect is the water quality improvement that arises from the removal of MTBE from gasoline. Additional information is needed to ensure that the substitution of ethanol for MTBE does not pose additional problems, particularly the increase in evaporative emissions due to the commingling of gasoline with and without ethanol in fuel tanks.

# COMMENTS ON PROPOSED CHANGES TO THE PREDICTIVE MODEL

The predictive model applies separately to exhaust and evaporative emissions. The development and use of the model are described in four main places in the staff report. A portion of chapter three summarizes the overall changes to the model. The attachment to Appendix A contains the regulatory language (and calculation procedures) for using the predictive model. The basis for the exhaust model is described in Appendix J and the basis for the evaporative model is described in Appendix K.

The main changes to the predictive model are the addition of an evaporative element, which predicts the total of evaporative and exhaust hydrocarbons, and the use of variable Reid vapor pressure (RVP), which provides refiners more flexibility in producing gasoline that meets the proposed regulations. These changes are particularly important since the only oxygenated compound allowed by the proposed regulations is ethanol, which is known to cause an increase in evaporative emissions due to its increase in RVP. In addition to these changes, new regression equations were developed which were based on an expanded database for the model. The revised predictive model also considers the effect of CO emissions in the formation of ozone. The effect of this added provision is to allow an increase in RVP when oxygen is added to the fuel. This provision makes it easier to use ethanol in gasoline. Ethanol is known to cause an increase in RVP, but the oxygen it provides will give it a credit to offset part of its RVP increase.

## Exhaust Emissions Methodology

Regression analyses were used to determine the effect of fuel properties on emissions. The data on various vehicle classes were subdivided into three different technology groups. Tech three consisted of all vehicles with model years between 1981 and 1985. Tech four contained model years between 1986 and 1993. Tech five covered model years 1994 and later.\* Separate regressions were obtained for each technology group.

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\*These model year divisions were taken from Table 2 in Appendix J which compares the technology group specifications for the previous and proposed predictive model. In two other places in the report, Table III-2 on page 27 of the main report and Table 2 on page 10 of the predictive model description in Appendix A, tech four ends at model year 1995 and tech five includes model years 1996 and later.

Mixed models were used. In these models the effect of the fuel is analyzed in the regression. Differences among vehicles are treated as a random effect that contributes to the overall variation in the data. Seven fuel properties were used: RVP, T50, T90, aromatic content, olefin content, oxygen content, and sulfur content. The regression model considered 35 possible terms: seven linear terms in the fuel properties, seven pure quadratic terms in the fuel properties, and 21 mixed quadratic terms in the fuel properties. The linear terms were always assumed to be present. The quadratic or second-order terms were included or excluded based on the results of the regression analysis.\*

The original analysis of the tech four vehicles gave counterintuitive results: hydrocarbon emission increased with increasing oxygen content of the gasoline. Such counterintuitive results are not uncommon in multivariate regression analysis, particularly when the independent variables are correlated.\*\* To eliminate this counterintuitive result, the staff devised a method to identify high influence vehicles. Once this was done, the vehicles with the highest influence on the results were eliminated and the regressions were redone. The report does not have any discussion of what a high-influence vehicle was. Conventional methods for detecting data with high influence on regression results (e.g., DFBETAS) and predictions (e.g., DFFITS or Cook's D) typically use some measure of the variance, which was not used to determine influential observations in the staff report. Although there is no general agreement on an exact threshold for an influential variable, the use of a conventional measure would provide a more meaningful understanding of how influential the deleted observations were.\*\*\*

Even with the deletion of high influence vehicles, counterintuitive results were still obtained. Staff then considered that the models had been overfitted. That is, several variables had been added, which would improve the fit of the model to the existing data, but would not improve the prediction efficiency for new vehicles. This consideration resulted in a revised approach whereby the terms of the old model were used and new coefficients were obtained by fitting the old model to the new database. In this approach, part of the data – a randomly selected 20% of the data – was excluded from the regression analysis and was used to determine the prediction error. When this approach resulted in similar prediction error for both models, the existing model was used with both the old and the new data. The report does not say if any of the data eliminated previously was put back in this final approach. Since the removal

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\* Several tables in this appendix list regression coefficients with the heading "Second-Order Term" in the first column. This heading is incorrect. A comparison of the tabulated values with the regulatory language for the predictive model in Appendix A shows that the rows with a single term in the first column (e.g., RVP, T50) give the results for linear or first order terms.

\*\* Thomas P. Ryan, *Modern Regression Methods*, John Wiley, 1997, page 131 *et seq.*

\*\*\* Thomas P. Ryan, *op. cit.*, pages 84-88.

of high-influence vehicles did not achieve its stated purpose of eliminating counterintuitive results, it may have been possible to consider all the new data in this final approach.

The mean prediction error shown in table 16 of Appendix J does not list units for the error. The error terms, for HC and NOx, range from 0.70 to 0.78. The tech four NOx equation, using the flat limit properties (with the oxygen content at 2%w), gives a NOx value of 0.52 grams per mile, which is less than the prediction error term, if that term is in grams per mile.\*

Other than the discussion of the prediction error in Table 16, there is almost no discussion of the statistical uncertainty in the predictive model. The sample output from the SAS run shows that RVP, T50 and T90 do not have regression coefficients that are different from zero with any statistical confidence. The p-values that the RVP, T50 and T90 regression coefficients are zero are 0.14, 0.67, and 0.21, respectively. The report does state that the linear terms are always included in the model, even if they are not statistically significant, but no rationale is given for this decision. (This is only done for HC and NOx; it is not done for exhaust toxics.)

## Evaporative Emissions Methodology

The evaporative emissions are also computed from regression equations. Here, the results from EMFAC7G, which give the various evaporative emissions (diurnal, resting, running and hot soak) for different values of RVP, have been used. The EMFAC7G results are recomputed as the percent change from the emission with an RVP of 6.9 psi and this percent change is then regressed against RVP. This approach hides the fact that the EMFAC7G results were obtained from regression equations based on an original data set. Presentation of the original regressions, or redoing the original regressions in terms of a percent reduction, would allow the reader to evaluate the uncertainty in the regression results.

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\* Reviewing the calculation procedure in Appendix A shows that the regression equations in Appendix J give the natural logarithm of the gram-per-mile emissions instead of the emissions themselves. This should be explicitly stated in Appendix J.

## Use of the Predictive Model

The instructions for using the predictive model are contained in Appendix A of the staff report. These procedures use several weighting factors that are based on the overall gasoline-powered motor vehicle inventory for 2005. The ARB mobile source inventory is now in a state of flux. The new inventory method, still in draft form, has recently been renamed from EMFAC 99 to EMFAC 2000. This new inventory was used for some calculations in Appendix H of the staff report, discussed below. The old inventory numbers have been used to develop the various weighting factors in Tables 4, 5, and 10 of the predictive model. Will these weighting factors be revised when EMFAC 2000 becomes the official inventory?

This review noted several minor points about the description of the predictive model in Appendix A.

- The definitions of technology groups four and five in Table 3 are not consistent with the definitions in Table 2 of Appendix J. They are, however, consistent with Table III-2 on page 27 of the main report.
- The equations for  $\ln(y_{\text{tech}})$  and  $y_{\text{tech}}$  at the top of page 20 do not include second-order terms. This may not be important since this portion of the model description is only giving a general form.
- The two equations for toxics at the bottom of page 22 would be clearer if the summations were written as  $\sum_q$  or  $\sum_{q=1}^4$  instead of  $\Sigma$  with no limits.
- The second-order RVP-T50 term at the bottom of page 24 could be written as a linear term in T50 and combined with the existing T50 term. This would be consistent with the treatment of other RVP terms in the regression equations.
- The term  $\text{OXYGEN}_{(\text{LIN})}$  is introduced on pages 26 and 27; a similar term,  $\text{T90}_{(\text{LIN})}$  is used on pages 31 and 33. Although the use of these terms is explained in the procedures, no reason is given for their use at any other point in this report.
- On pages 45 and 46 the term for oxygen as EtOH should have the variable "(Term)" inserted between the regression coefficient and the standardized oxygen variable.

The substitute fuel is determined to be equivalent to the fuel meeting the full specifications if the increase in emissions is less than or equal to 0.04% for all components. There is no explanation of why this figure was chosen instead of an alternative such as 0.05%, 0.00% or -0.04%. It would be interesting to have data on the statistical properties of the regressions that would allow the computation of the confidence limits for the actual percent increase.

## **COMMENTS ON OTHER APPENDICES**

The appendices to the staff report contain a variety of materials. Some appendices contain material prepared as part of this staff report to provide additional detail for points in the body of the report. Other appendices contain reference material. The latter appendices were generally not reviewed in detail. All appendices are listed below with specific comments or an indication that no detailed review was conducted.

### **Appendix A – Proposed Amended Regulations**

This appendix contains the formal regulations discussed in the report. This section was not reviewed in detail. The revisions to section 2262, which place the various limits in a table while eliminating repetitive sections for limits of various properties, help to clarify the regulations. This appendix also contains the regulations for the implementation of the predictive model. Comments on this part of Appendix A were covered in the previous section of this review.

The staff report, on page 23, proposes a restriction on all ethers and alcohols, except ethanol, unless a multimedia evaluation of the environmental impacts show that the use of a particular compound or compounds will not cause a significant adverse impact on public health or the environment. Section 2262.6(c) contains the restriction on ethers. However, this reviewer could not find the regulatory language with a similar ban on alcohols.

Several definitions in section 2260 use the abbreviation PM to refer to the predictive model. This is confusing to the reader who usually sees this abbreviation used for particulate matter.

### **Appendix B – ARB Review of University of California Report on MTBE**

This memorandum, dated February 22, 1999, was briefly reviewed. It does not appear to contain any information that directly bears on the recommendations in the body of the report.

### **Appendix C – Governor Davis's Executive Order on MTBE**

This executive order is a useful reference, but does not require any review.

## **Appendix D – California Energy Commission Timetable for Phase Out of MTBE**

The June 1999 CEC report in this appendix contains several findings regarding the deadline for the elimination of MTBE from gasoline in California. The time required for refinery modifications to produce phase three gasoline was estimated to range from 33 to 42 months. This assumes that the environmental review process under the California Environmental Quality Act (CEQA) for these modifications could be completed in one year. The proposed December 31, 2002 deadline for the removal of MTBE and the implementation of the other phase three requirements is just under 37 months from the proposed adoption date of December 9, 1999.

The CEC report also notes that the demand for ethanol to replace MTBE in California may range from 35,000 to 92,000 barrels per day as compared with the current US production capacity of 100,000 barrels per day. The reopening of existing facilities that are currently idle would require about six months and would add about 20,000 barrels per day of ethanol capacity. The CEC report estimates that two to three years would be required to start new ethanol production facilities. Such new facilities would likely be required even if no other state required the removal of MTBE from gasoline. The combination of other states requiring MTBE removal and the absence of any change to the Clean Air Act requirement for year-round oxygenated compounds in gasoline would increase the need for additional production facilities.

The implementation schedule for the phase three requirements (including MTBE removal) does not provide any safety margin in the time required for refinery modifications and the additional ethanol production facilities. Refiners who cannot meet this schedule will have to seek a variance from the regulations. The wording of section 2271 of the regulations has been modified to provide the opportunity for a variance if refiners cannot comply with the December 31, 1999 deadline.

## **Appendix E – Correspondence on Waiver from Federal Clean Air Act Requirement for Oxygenated Fuels**

This correspondence states the rationale for granting a waiver to the federal requirement for year-round use of oxygenated gasoline. It was not reviewed in detail.

## **Appendix F – Analysis of CO Exceedances in the South Coast Air Basin**

One provision of the proposed phase three regulations would exclude October from the period when oxygenated gasoline is required in the South Coast Air Basin. This would provide more flexibility to refiners in meeting the RVP standard in October. The analysis in this appendix estimates the effect of this provision on the attainment of the ambient air quality standard for CO.

The basic conclusion of the analysis is that the ambient concentrations of CO will continue to decrease whether or not oxygenated gasoline is used. This analysis is based on a simple dispersion model in which the predicted ambient concentration is directly proportional to emissions. Although the analysis appears to justify the final conclusion, there are several minor points that should be clarified.

1. The "total" inventory data presumably includes stationary, area, and other mobile sources. The column headings in the tables imply that all the inventory data come from MVEI7g or EMFAC99.
2. There is no explanation of how the concentration of 9.69 for 1997 was determined. Presumably the concentration was 9.69 ppm and was obtained from measurements at the Lynwood station.
3. The motor vehicle inventories were presumably run for a 24-hour period to get the tons/day data rather than an eight-hour period that would be consistent with the concentrations.
4. The assumption that the removal of oxygen would increase CO concentrations by 10% appears to be a worst-case estimate. Data on CO increases shown in Appendix G show much smaller increases, particularly for modern vehicle technology.
5. For purposes of this appendix, the mobile source inventory should be limited to gasoline-powered vehicles.

These minor points will not have a significant effect on the overall conclusions of this appendix.

## **Appendix G – Carbon Monoxide Credit Estimation**

The addition of oxygen to gasolines can lead to a decrease in carbon monoxide, particularly for older-technology vehicles. The use of ethanol to provide this increase in oxygen can lead to an increase in evaporative hydrocarbon emissions. The increased HC emissions and the decreased CO emissions have opposite effects on the photochemical reactions that produce ozone. This chapter estimates the offsetting effects from these two mechanisms.



There are two steps to this analysis. The first step is the estimation of the reduction in CO emissions. This was done by examining data from the Auto/Oil program and from the ARB study that examined the effects of ethanol. Based on these studies the staff calculated the changes in CO emissions for five different vehicle technology classes when the oxygen is increased or decreased by one percentage point.\*

Separate analyses were performed for increases and decreases in CO. There is no explanation why these separate analyses were done. The magnitude of the changes observed in Tables 1 and 2 on page G-2 are similar; the greatest discrepancy is for the Tier 3 vehicles for which the CO increases by 5.8% for a one percentage point increase in oxygen and decreases by 5.1% for a one percentage point decrease in oxygen. There is no data on the oxygen level at the start of the increase or decrease, but statements in other parts of the report imply that the starting point was an oxygen content of 2%w.

The percentage changes for various technology classes are then applied to the emissions data for 2005 from the EMFAC7G mobile source inventory model to determine the CO reductions obtained from a one percentage point increase or decrease in CO emissions.

The decrease in CO emissions is then translated into a decrease in ambient ozone by using a reactivity factor of 0.07 grams of ozone per gram of CO. The reactivity factors for evaporative and exhaust hydrocarbons, which are 2.21 and 3.35 grams of ozone per gram of hydrocarbon, respectively, are then used to determine the equivalent change in these emissions that would produce the same reduction in ozone

The results of this analysis, using the direct CO emissions data from EMFAC7G, show a decrease of 106 tons/day of CO, which is equivalent to a decrease of 7.41 tons/day of equivalent ozone. This equivalent ozone reduction could be achieved by a reduction of 3.22 tons/day of evaporative hydrocarbons or 2.21 tons/day of exhaust hydrocarbons. These figures could change if the new mobile source inventory, EMFAC 2000, were used.

## **Appendix H – Driveability Index Analysis**

Appendix H describes the regression analysis used to determine the driveability index as a function of RVP, T50, and T90 in the absence of data on T10. According to the footnote on page H-1, the driveability index was computed from only the distillation

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\*The increase or decrease of one percentage point is assumed; it is not clear from the text. Also, the title of Table 2 in Appendix G should refer to a decrease, not an increase, in emissions.

temperatures; the oxygen concentration term in the driveability was not included. There was no discussion of why this term was not included and no data on oxygen concentration were presented.

This regression analysis was used to obtain estimates of driveability index for gasoline blends where the value of T10 was not known. Here the gasoline grade and the RVP were used as surrogates for T10. A better statistical approach might have been the development of a regression equation for T10 in terms of the RVP and the other distillation temperatures. This could have led to greater significance for the regression coefficients in the resulting correlations. The use of a regression equation for the driveability index is confounding the correlation that the distillation temperatures, T50 and T90, have with both T10 and with the driveability index.

## **Appendix I – Statistics on 1998 Gasoline**

This appendix describes the procedure used to compute the in-use average properties for phase two reformulated gasoline in 1998. It is not clear how these data were used in the report. They do not correspond to the 1998 ozone-season, in-use fuel properties used in chapter five.

## **Appendices J and K – Development of the Predictive Model for Exhaust and Evaporative Emissions**

The previous section of this review discusses these two appendices.

## **Appendix L – Reactivity of Gasoline Vehicle Emissions**

This appendix describes the data used to determine the relative reactivity of exhaust and evaporative emissions in Table 9 of the predictive model description in Appendix A. These reactivities are also used in the CO credit calculations described in Appendix G. The text of the appendix notes that there appeared to be no variation in reactivity with fuel properties for specific emissions modes: exhaust, diurnal evaporative, hot soak evaporative, and evaporative running loss, except an increase in reactivity in diurnal emissions at higher olefin levels. To compensate for this variation, only data from fuels with less than 10%v olefins (the cap limits for both phase two and phase three) were used in the calculations.

The overall results – an evaporative reactivity factor of 2.21 and an exhaust reactivity factor of 3.35 – are based on a review of reactivity results for several studies. The

average evaporative reactivity factor is based on the distribution among evaporative reactivity modes for calendar year 2005.

## **Appendix M – Off-Road Emissions**

ARB staff found seven studies on off-road engines run on different fuels. Based on their review of these data, they concluded that it was not possible to quantify the interaction between CO and evaporative emissions for these engines.

## **Appendix N – Effects on Greenhouse Gas Emissions**

The calculations of greenhouse gas emissions in this appendix consider both the emissions from combustion of the fuel in the engine and the emissions from the fuel production. Although these fuel cycle emissions may be a significant component, the two studies reported in this appendix show that the fuel-cycle emissions are 13% or 23% of the total greenhouse gas emissions. This difference shows the uncertainties with the current analyses of fuel-cycle emissions.

## **Appendix O – Potential Economic Benefits of the Feinstein-Bilbray Bill**

The report in this appendix was prepared by MathPro Inc. for Chevron and Tosco. It is an extension of the analysis that MathPro did for the California Energy Commission as part of the study described in Appendix P of the staff report. The report examines the difference in cost for producing gasoline without MTBE. The analysis is done with and without the assumption that there is a waiver from the year-round requirement for oxygenated fuels from the federal Clean Air Act.

The main finding of this report is that the economic optimum gasoline production would use some amount of ethanol, regardless of the federal requirements for year-round oxygen content. A cost savings occurs, relative to the federal requirement for year-round oxygen, due to the flexibility that refiners have to optimize their refining process.

## **Appendix P – California Energy Commission Report on the Cost of MTBE Alternatives**

The CEC report contained in this appendix is actually the summary report. The details of the analysis are contained in a set of appendices that are not included here.

Without the details of the study, it is not possible to prepare a peer review of the results. The cost data from this CEC report are consistent with the ARB staff analysis of economic effects.

## CONCLUSIONS

This peer review was asked to provide “independent confirmation of the scientifically-based rationale used in the ARB staff report.” Furthermore this review was to consider “both the policy and technical basis for the proposed revisions.” The policy basis for the report is unusual for ARB staff reports that usually address air quality concerns as their major thrust. In this case the main environmental concern was the overall impacts from the use of MTBE in gasoline. The ARB staff report is responding to the Governor’s executive order that called for a ban on MTBE in gasoline. That executive order directed the ARB to implement regulations that provided flexibility in the removal of MTBE and maintained the current emission benefits of reformulated gasoline.

From a qualitative perspective the recommendations are sound. The changes in the requirements for the distillation temperatures T50 and T90 are directionally correct. These changes meet the desired goal of increasing refining flexibility in producing gasoline after the removal of MTBE. Similarly, an increase in the aromatics cap will help accomplish the same goal.

The reduction in the sulfur level of the gasolines will help reduce emissions. This is consistent with several recent studies on the effects of sulfur in gasoline. Similarly, the reduction of the gasoline benzene content will reduce the emissions of this carcinogen.

A major effect of the proposed regulations will be the substitution of ethanol for MTBE. This is likely to occur even if there is a waiver to the federal Clean Air Act requirement for year-round use of oxygenates in gasoline.

A final decision on the phase three requirements requires a judgement on the appropriate levels for the various specifications. The evaluation of the air quality effects shows that the phase three gasoline will provide reduced NO<sub>x</sub> and benzene emissions as compared with the phase two gasolines with MTBE. However, it is difficult to judge from the staff report how the final levels were selected to give an appropriate balance between benefits and costs.

The predictive model has been used to calculate the benefits of the proposed regulations. The staff report notes that about 75% of the gasoline produced in California is based on the predictive model. It would be useful to have more information on the statistical properties of this model so that the uncertainty in the model, on which so much of the California reformulated gasoline program depends, could be judged.